Combat Hybrid Power Systems

Future Combat Systems Technology Conference

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Dr. Marilyn Freeman

Defense Advanced Research Projects Agency (DARPA)/
Tank-automotive & Armaments Command (TACOM)-
Tank-automotive Research, Development & Engineering Center (TARDEC)

3701 North Fairfax Drive,

Arlington, VA 22203-1714

703-696-2376

mfreeman@darpa.mil

Mr. Dan Herrera

810-574-5552

herrerad@tacom.army.mil

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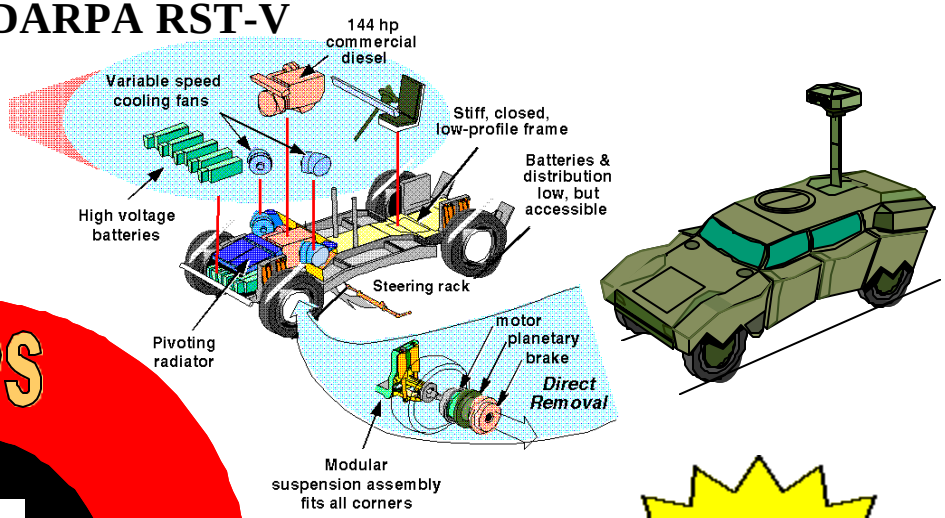
DARPA EV/HEV

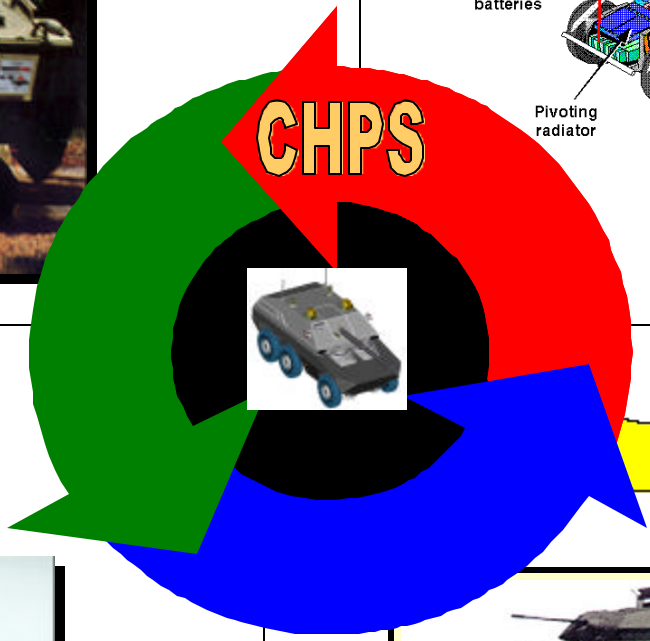
Technology Progression

DARPA EV/HEV - Electric M113

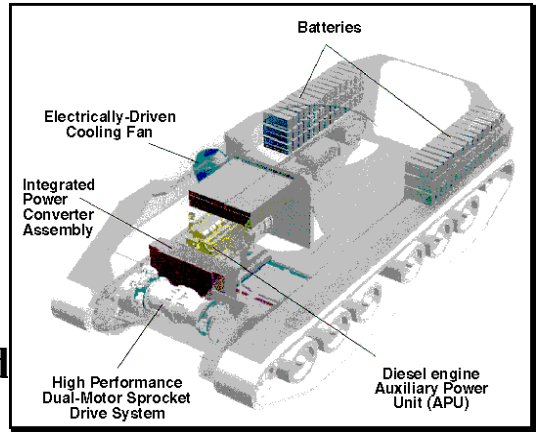
DARPA RST-V



DARPA EV/HEV - Hybrid Electric HMMWV



FCS



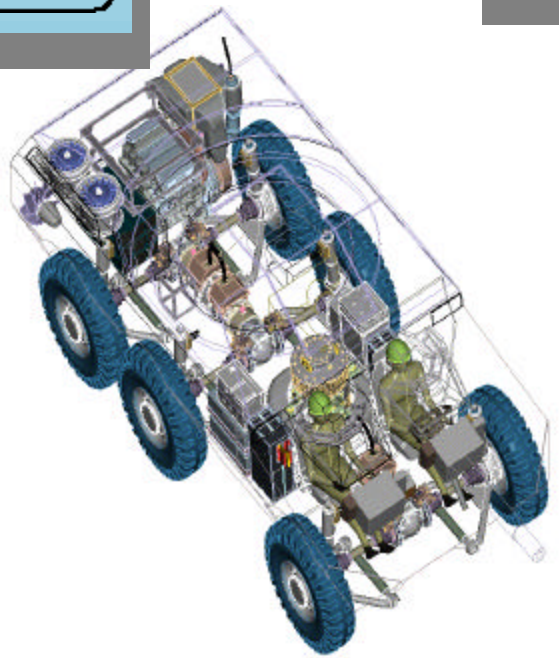
DARPA EV/HEV-Hybrid Electric Bradley

Combat Hybrid Power Systems (CHPS)

Hybrid System Architecture Allows:
- **Intelligent Energy/Power Management**
- **Advanced Electric Based Weapons**
- **Dynamic Armor, Active Protection, Countermeasures**

Multiple Propulsion/Power Sources
- **Allows Silent Watch & Mobility**
- **Enhances Dash Speed**
- **Ensures Battlefield Robustness**

Notional Vehicle (15 ton goal)



Reduced Signatures
- **Acoustic**
- **Thermal**
- **Visual**

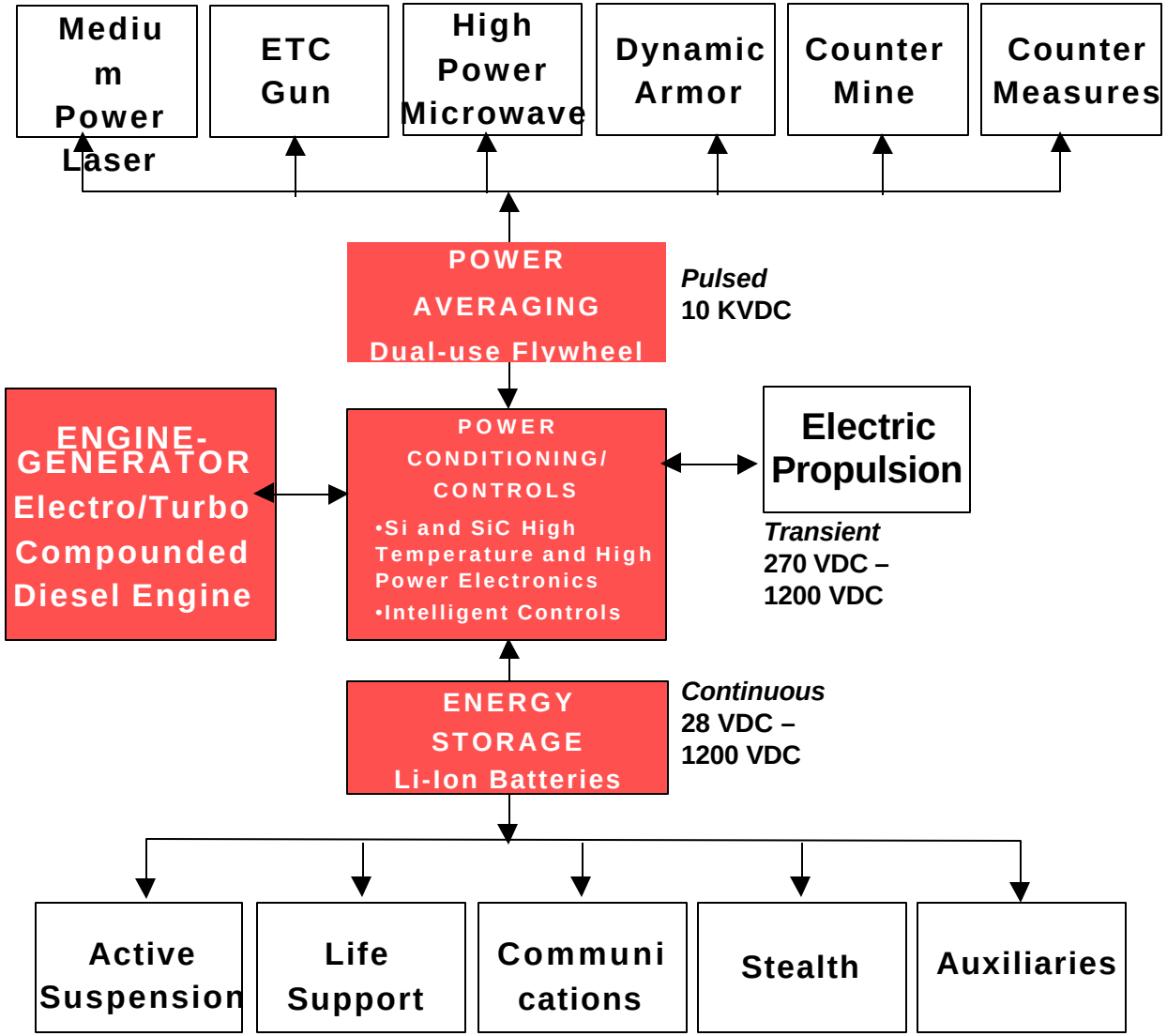
Electrical Power for Platform Mobility/Agility Subsystems :
- **Electromechanical Suspension**
- **In-Wheel Propulsion**
- **Differential Torque Steer**

$55M DARPA Investment since 1997

Enabling Technology for Future Combat Systems (FCS)

System Concept

Combat Hybrid Power Systems (CHPS)



The CHPS Vision

- **Reduce fossil fuel requirements 35-45% through lightweight, compact components and centralized power management/ conditioning**
- **Reduce total system weight (25-35%) & increase available payload volume (10-15%) through:**
  - smaller high temp components
  - centralized all-vehicle power distribution
  - Dynamic armor
  - layout flexibility

Technical Approach/Challenges
CHPS

Approach

- Develop critical technology components employing innovative design and fabrication processes
- Demonstrate technologies both independently and within an integrated mission architecture
- Develop physics/engineering models based upon real component testing that will become part of a "toolbox" that can be used for the design of future hybrid electric combat vehicles

Technical Challenges

- Develop affordable, efficient, high-power electrical system architectures and components to generate power, store energy, condition power, and distribute both 100's of kilowatts continuous and multi-gigawatts pulsed power to subsystem loads

Enabling Technologies	Beginning (1997) State of the Art	Original Program Goal	Current Status
Prime Power (diesel engine)	0.7 kW/kg 0.65 lb/hp-hr	0.7 kW/kg >0.32 lb/hp-hr	Preliminary design to reach goal verified by modeling
Energy Storage (batteries)	300 W/kg 80 W-hr/kg	1250 W/kg 120 W-hr/kg	1000 W/kg, 100 W-hr/kg nominal, over 4000 W/kg demonstrated.
Pulsed Power (flywheel)	1.1 kW/kg 0.8 W-hr/kg	2.5 kW/kg 1.9 W-hr/kg	4.8 kW/kg, 6.7 W-hr/kg design supported by tests
Silicon Carbide Switches	1200 V, 600 A, 140°C, 20 kHz (Device)	1500 V, 1000 A, (Device)	10,000 V, 150 kW, 300°C, 100 kHz, full dc-dc converter in progress

Systems Integration Laboratory (SIL)

Combat Hybrid Power Systems (CHPS)

Flywheel (3)

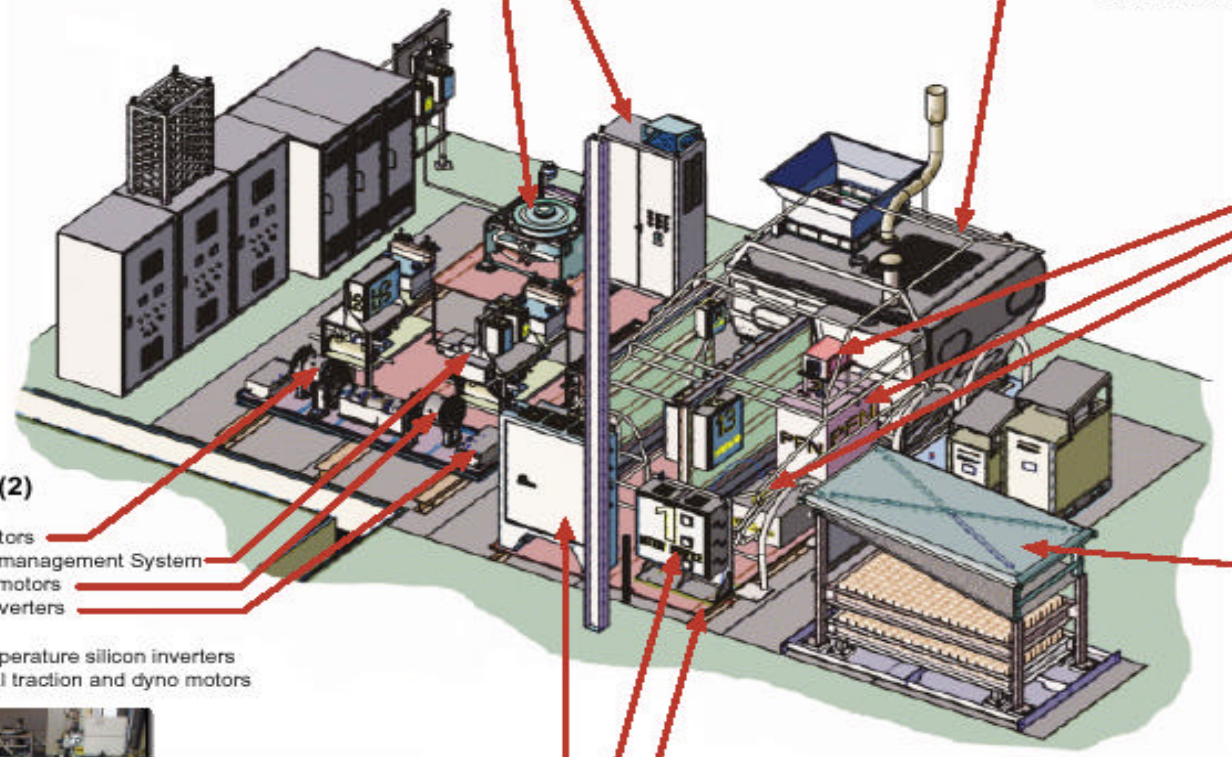
Today
- Magnet Motor controller
- Magnet Motor flywheel

Future
- CHPS flywheel

Prime Power (4)

Today
- Caterpillar 3126 diesel engine
- Direct drive induction generator
- Heat Exchanger
- Cooling Fan

Future
- Hi-Speed diesel
- Electric turbo-compounding



Pulsed Power and Loads (5)

Today
- Resistive ETC load
- DTRA PFN
- DC-DC converter

Future
- DARPA/TACOM PFN
- Resistive EM Armor load
- Real EM Armor load
- ETC tap-off
- Resistive ETC load
- Dynamic ETC load simulator
- **Silicon Carbide DC-DC converter**

Mobility (2)

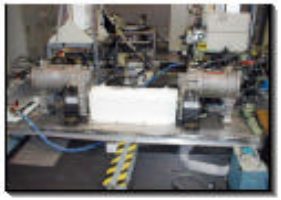
Today
- Dyno motors
- Thermal management System
- Traction motors
- Silicon inverters

Future
- High temperature silicon inverters
- Additional traction and dyno motors

Batteries (6)

Today
- Nickel Cadmium battery

Future
- Lithium Ion battery



EMI (7)
- Sensors
- Data acquisition

Power Distribution (1)

Today
- Power Distribution Box
- Battery Interface Box
- Floating ground (red floor)

Future
- Enhanced shielding

June 2000

Vehicle Integration & Performance – Design Tool Set (VIPER-DT)

Input Requirements:
- Mission
- Weight
- Volume

OUTPUT:

3D CAD Model Components
- **Prime Power**
- **Energy Storage**
- **Pulsed Power**
- **Primary Loads**
  - **+ Mobility**
  - + Weapons
  - + Defensive
- Auxiliary Loads

Performance Capabilities and Results

CHPS VIPER Toolset provides high-confidence, validated, fully integrated vehicle design and performance results within a specified weight and volume envelope

Combat Hybrid Power Systems
(CHPS)

CHPS develops enabling component technologies, conducts experiments and provides cost-effective demonstrations of *integrated* hybrid electric power systems that provide energy/power for *all electric subsystems and loads* in future combat vehicles.

Objectives are to develop, understand and demonstrate:

- Power system architectures & control strategies that will maximize fuel economy for diverse driving conditions, reduce fuel logistics (>=50% over current vehicles in same wt. class) and maximize mobility/agility for various FCS missions (>=60mph over most terrains with high speed dash capability)
- Ability of one integrated system to provide power to *multiple* electric loads (armor, AP, electric guns, lasers, HPM, etc.) – to have the power where and when it is needed – and predict vehicle performance with virtual prototype
- Advanced system components (batteries, switches, suspensions, wheel motors, thermal management system, etc.) of significantly reduced wt. & vol. & high efficiency

Through:

- Hardware-in-the-loop experiments and demonstrations in a Systems Integration Laboratory (SIL) with full instrumentation and flexibility to reconfigure
- Development of component technologies: energy storage, pulse power, mobility, prime power, electronic control/power management
- Virtual Prototype that is validated by SIL and that enables vehicle design trades for 4 to 40 ton combat systems

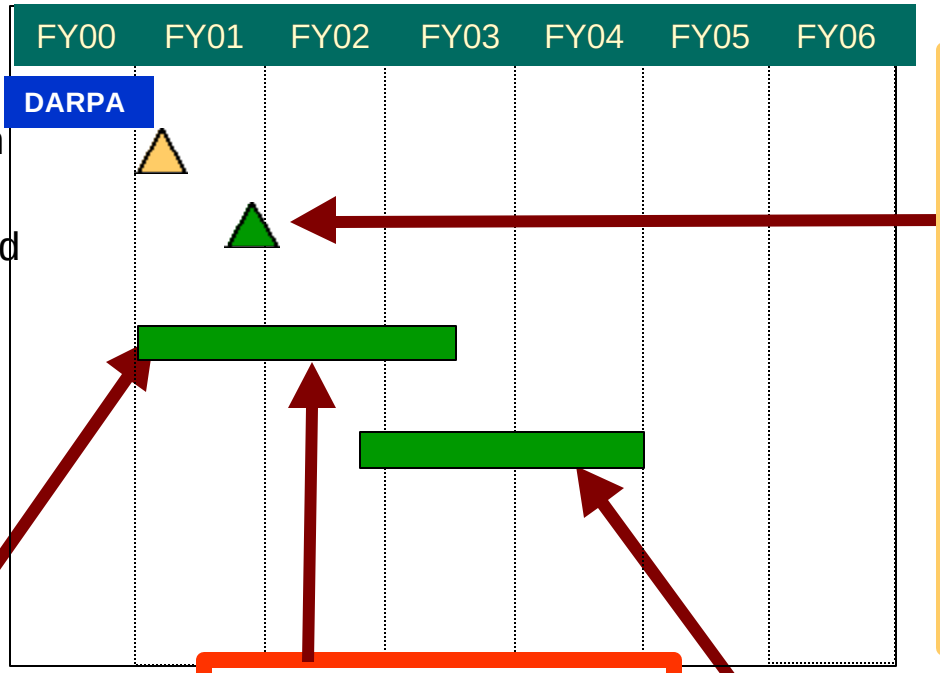
Essential for light weight, lethal, survivable future combat vehicles

Detailed Program Schedule

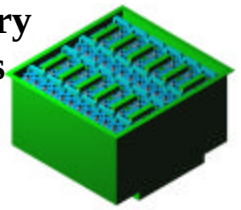
Combat Hybrid Power Systems

Activities

- DARPA SIL Demo
- Program Transition to Army
- Complete advanced components insertion
- Conduct experiments and trade studies
- CHPS SIL Operation, Experimentation & Demos



CHPS Battery Packs

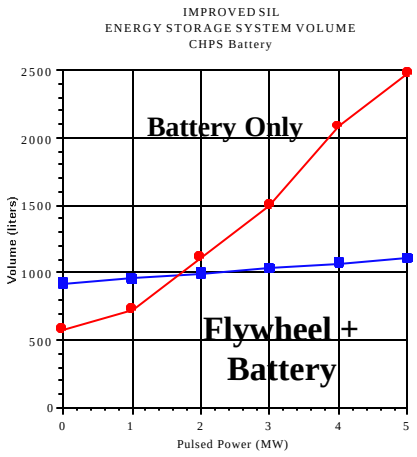


12 Modules in series, 72S-2P, 260V @ 60AH (2 needed for 520 V SIL replacement of NiCds)
Weight - 200kg (440lbs) approximate
Dimensions - 406mm (16in) x 685mm (27in) x 736mm (29in)

Breadboard Test -TRL 5

- Demonstrate power architecture(s) in SIL w/ best available components.
- Complete advanced component testing (batteries, switches, wheel stations, etc.).

Trade Studies



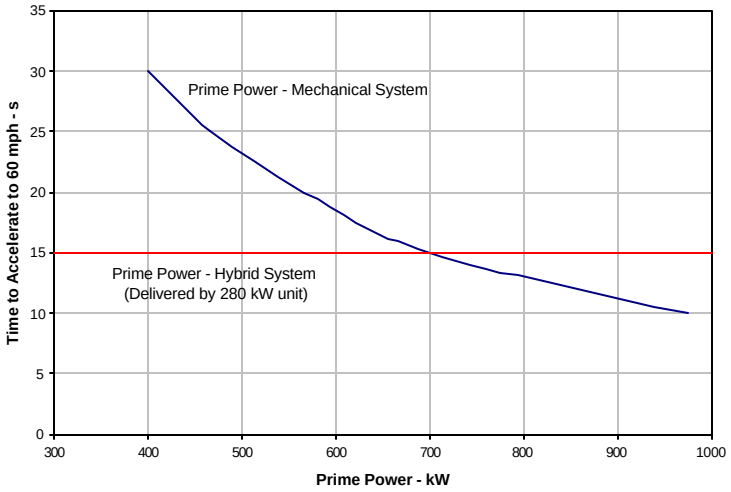
Brassboard Test -TRL 6

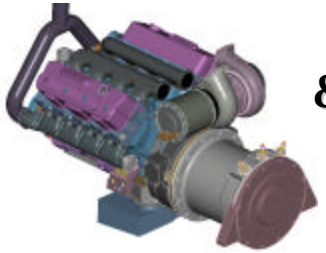
- Demonstrate power system architecture in SIL with advanced components.
- Use experience and understanding in design and performance of hybrid combat vehicle to feed FCS ATD(s).

Using This New Capability

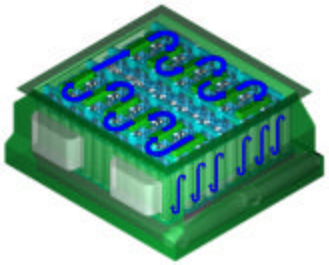
Combat Hybrid Power Systems (CHPS)

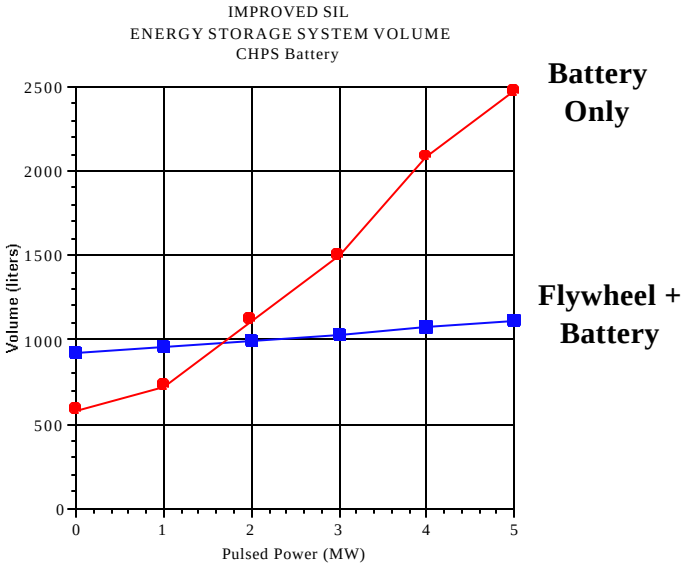
CHPS transitions to U.S. Army TACOM/TARDEC in FY01





Prime Power & Hybrid System Efficiency





Flywheel / Battery Trade Studies

CHPS provides affordable ways: 1) to gain critical basic understanding of control strategies, component technologies, hardware interface issues, EMI/EMC, operational signatures, synergies of subsystems, etc. and 2) to conduct design trades for hybrid electric combat vehicles in time to make decisions for Future Combat Systems program.

TRL Rationale

Combat Hybrid Power Systems

Hybrid Electric Power Systems *are* at TRL 5 today; by end FY02 TRL 6 for mobility

- By using the SIL and VIPER-DT (model) together, CHPS *is* the simulation environment that provides demonstration of components and predicts performance
- Several prototype hybrid electric combat vehicles are in development or in testing and auto manufacturers are putting HEV on the market
- SIL reconfigurability allows flexibility in architecture to represent a variety of FSC vehicle configurations, eliminating need to build multiple variants of Hybrid Electric Vehicles to assess feasibility or performance benefits

- **CHPS provides opportunities for several advanced lethality and survivability technologies to plug in and demonstrate TRL levels of 5 or 6 (from a power system perspective)**

- **Subsystems and component technologies (providing increased capability per vehicle volume or weight) are at different TRLs ranging from batteries @TRL5 to MW flywheels @TRL3 to MW switches @TRL3 to fuel cells @TRL 3-4.**

CHPS Program Status

- SIL 90% complete with current component technologies
- Demonstrated ability to successfully operate integrated system
- Demonstrated power sharing and power management through DC bus
  - Diesel Engine (375 hp)
  - NiCd batteries (312 V)
  - Magnet Motor flywheel
  - Pulse forming network for ETC static load

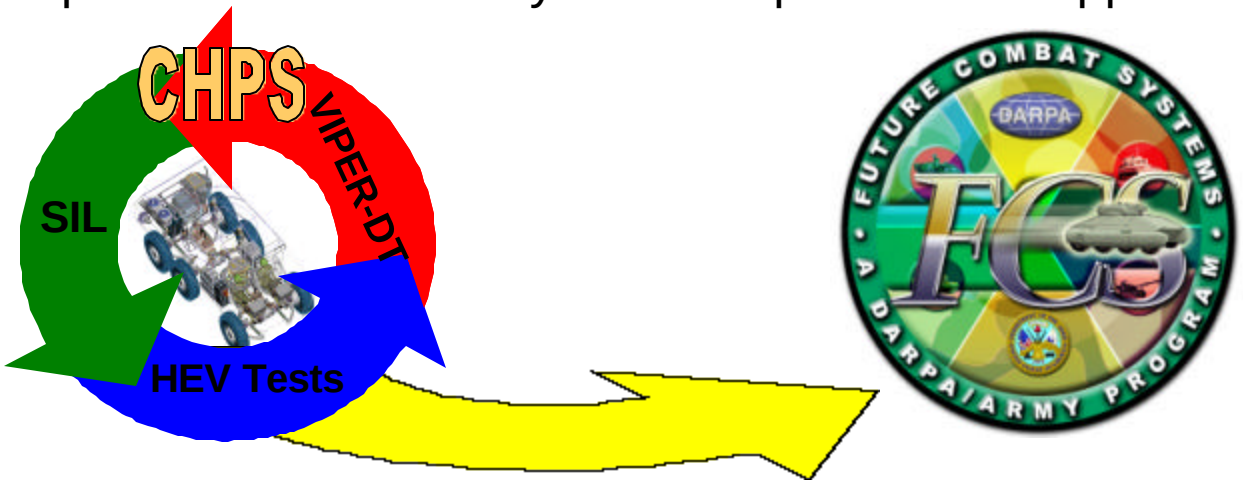
- Component technology development
  - No serious setbacks – no show stoppers
  - SiC DC/DC converter diodes and GTOs made; assembly tricky
  - Hi T Si motor controllers in test
  - 1st of 2 Li Ion battery packs checked out and delivered to SIL

- Agreements with EM Armor program and ETC (PM-TMAS) to demonstrate Dynamic loads in SIL with one PFN for both.
- Transition to TARDEC on schedule for end 2000.

Summary

CHPS is geared to provide critical data, analyses and conclusions about hybrid electric combat vehicles to support FCS decisions in FY04 and beyond

- DARPA focus was on technology development and proof of principle that flexible hybrid electric architectures and virtual prototypes can be developed and components integrated into a system that can be used to gain essential experience and understanding without building multiple prototype vehicles.
- Army focus will be on exploiting the facilities and capabilities as well as continuing development of advanced system components to support FCS decisions.



BACKUP

Combat Hybrid Power Systems (CHPS)

1. Problem: Army desires light weight (<=20 ton), lethal, survivable, highly mobile/agile, multi-mission platforms demands new design paradigm that takes full advantage of synergies offered by hybrid electric vehicle systems. Need for significantly:

- improved vehicle fuel economy (reduced logistic demand to refuel) and improved acceleration and maneuverability
- reduced vehicle signature (stationary & mobile)

2. Barriers: Hybrid system architecture & control strategies for complex power systems; Thermal management systems of min. wt. & vol.; High T power conditioning & switching; High energy density electrical storage devices; High power density motors & generators, Efficient power conversion

3. Approach: Conduct experiments, trade studies and demos in re-configurable, hardware-in-the-loop SIL & use verified virtual prototype to design combat vehicles (4-25Tons) and predict performance without cost of multiple vehicle prototypes

4. Capability: Capabilities developed to support: AR 97-008 Electrical Power Generation, Storage, and Distribution; MMB 97-006 Power Generation; IN 97-113 Lethality - Infantry Direct Fires-Directed Energy; IN 97-300 Mobility - Tactical Infantry Mobility; IN 97-301 Mobility - Tactical Infantry Deployability; AR 97-005 Advanced Propulsion

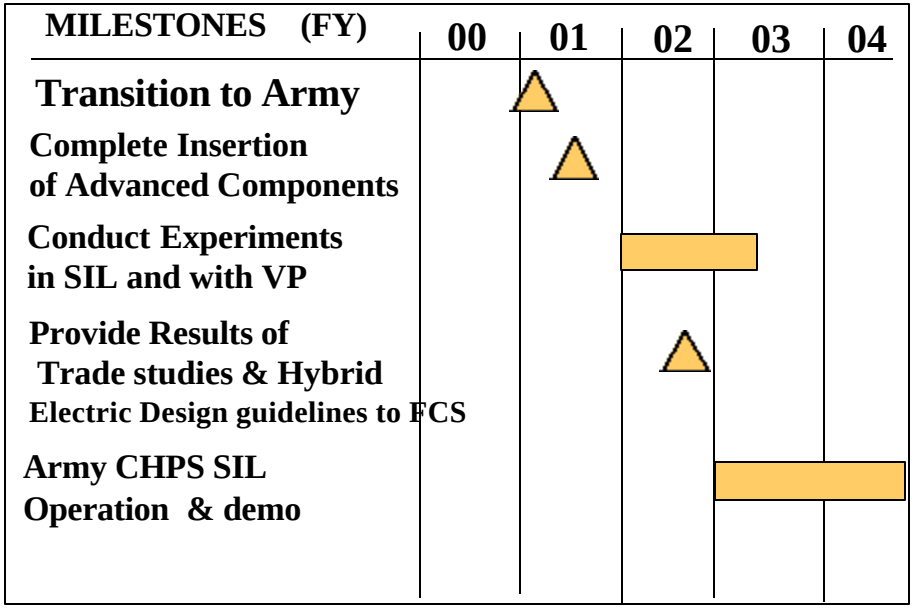
5. Products:

- Tools to design & demonstrate combat vehicles with advanced weapons and protection systems in cost effective manner - System Integration Laboratory (SIL) & Virtual Prototype
- Results of trade studies, design guidelines and basis for deciding to accept hybrid electric vehicles as FCS solution
- Smaller, lighter combat vehicle subsystems through advanced component technology development

6. Metrics:

- % Reduction in total system wt & vol. (over platforms with comparable capability)
- % increase in speed and maneuverability

SCHEDULE AND FUNDING:



7. WARFIGHTER PAYOFFS: The development of hybrid electric power systems is an enabler for Future Combat Systems (FCS). It will result in more capable platforms with greatly reduced noise & thermal signatures; improved mobility, survivability, lethality & fuel economy. These advantages will result in deployable, affordable combat vehicles that are rapidly deployable and can meet mission requirements.

8. Transition Milestones: Complete component level testing of technologies being developed by the 4Q03. Experimentation with power system architecture and controls in SIL in the 2Q04. By the 4Q04, complete transition of power system architecture to the next planned Army vehicle ATD.

9. Endorsements: PM Bradley; MMBL; DCD-CSS; DCD USADASCH; DCD, USAIC

10. Non Army Funding: Leveraging FY 97-00 DARPA CHPS investments in Electric Drive, High Temperature SiC switching, & developments in advanced power technologies.

Technology Maturity

Technology Title: Combat Hybrid Power Systems

Attributes	Objectives						
	Units	FCS Best Estimated need	Current (CHPS SIL)	April 2003		April 2004	
				Status	Risk	Status	Risk
Performance							
Prime Power	kW/l	0.8	0.33	0.8	M	0.8	M
	kW/kg	0.7	0.5	0.7	M	0.7	M
	lb/hp-hr	0.32	0.38	0.35	M	0.32	M
Pulsed Power	kJ/l	0.67	0.20	0.40	L	0.67	M
	kJ/kg	0.50	0.07	0.25	L	0.50	H
	A/J	2.5	0.22	4.0	L	2.5	M
Battery	kW/kg	1.4	0.57	1.0	M	1.4	M
	Wh/kg	100	58	100	M	100	M
	Wh/l	200	63	200	M	200	M
Flywheel	kW/kg	15	0.3	4.8	M	9.6	M
	Wh/l	20	3.7	10.3	M	10.3	M
Converters	kW/l	40	25	35	M	40	M
	kW/kg	20	12.5	17.5	M	20	M
Physical							
Prime Power	liters	350	800	350	M	350	M
Pulsed Power	liters	300	200	1000	M	300	M
Battery	liters	250	200	250	M	250	M
Flywheel	liters	350	534	674	M	674	M
Converters	liters	25	48	34	M	30	M